PATENT SPECIFICATION

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COMPLETE SPECIFICATION

DRAWINGS ATTACHED

Electric Surface Heaters

We, D. NAPIER & SON LIMITED, a Company registered under the Laws of Great Britain, of 55, The Vale, Acton, London W.3. do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electric surface heaters for example for heating the windscreen and canopy surfaces or wing surfaces or other surfaces of an aircraft to prevent or to remove ice or fog.

According to the present invention an electric surface heater comprises a plate of elecrically non-conductive material, and a plurality of discrete sections of conductive material coated on said plate defining a heated area of non-rectangular shape, the thickness of the material of all these sections being the same and the sections being electrically connected in groups each comprising two sections in series, the groups being connected in parallel across supply terminals.

This arrangement of individual sections of a heater enables the heater to be designed for application to an irregular surface while facilitating the maintenance of a substantially constant or controlled power dissipation throughout the heater and yet having a coated conductive material of uniform thickness.

In the past there has been no difficulty in achieving this result with a square or rectangular surface because if the energising electric supply is connected to bus-bars along two opposite parallel sides, the power dissipation is uniform with a uniform conductive coating. This is particularly advantageous where the surface being heated is a transparent surface such as a windscreen or canopy because varying thickness of the conductive coating over the transparent surface will make light transmitting properties irregular and thus make clear vision difficult.

The invention has particular application to surfaces of tapered shape and then the individual sections can be trapezoidal in shape, each succeeding section having a shorter distance separating the mid-points of its non-parallel sides.

The first and last sections are conveniently connected as a pair in series and the sections of each inwardly succeeding pair may also be connected in series, each pair constituting one of the said groups.

With a heater of this form almost precisely uniform power dissipation can be achieved if the widths of the sections perpendicular to the direction of current flow, that is to say perpendicular to the parallel sides of the trapezium, are equal. According to a preferred feature of the invention the widths of the sections are varied as between one group and another, and the widths may be selected at values within limits determined by the maximum and minimum tolerable power density, as explained in greater detail below.

The maintenance of uniform power dissipation over the surface allows the coating to be thick enough for the generation of sufficient heat to maintain the surface at a desired temperature without exceeding a maximum power dissipation anywhere while yet the coating can be uniformly thin enough to permit sufficient light transmission where the surface being coated is transparent.

The invention may be carried into practice in various ways and one embodiment will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a top plan view of a panel constructed in accordance with the present invention;

Figure 2 is a schematic diagram showing the electrical equivalent of the panel of Figure 1, and

Figure 3 is a geometrical representation of the panel shown in Figure 1.

Referring now to Figure 1, there is shown a non-rectangular conductive panel, generally indicated at 10, constructed according to the present invention. A tapered plate 12 of glass or transparent plastic has deposited or coated thereon a plurality of sections 14, 16, 18, 20, 22, 24, 26 and 28 of a conductive material. This material may, for example, be a transparent conductive coating of the type formed from the vapours of a mixture of stannic chloride, water and methanol, or maybe of vapour-deposited gold. The coating or film may be deposited on the entire surface and the isolation lines scraped out or otherwise removed to divide the coating into discrete sections, or the plate may be suitably masked and the conductive material then coated on the plate.

Each of the sections 14-28 is in the shape of a trapezoid, one of the non-parallel sides of each trapezoidal section lying along a first common line and the other non-parallel side of each of the trapezoidal sections lying along a second common line. As illustrated, each of these sections is in the form of a right trapezoid which for the purpose of this specification is defined as a trapezoid having one non-parallel side perpendicular to the parallel sides, this one side being referred to as the right side and the other non-parallel side being referred to as the sloping side. This configuration results in each succeeding section (from right to left as shown) having a lesser distance separating the mid-points of their non-parallel sides.

The sections 14, 16, 18 and 20 are electrically connected together by means of a conductor 30. This conductor preferably takes the form of a silver bus-bar 30 painted on the plate 12 along the line in which lie the right sides of the sections 14, 16, 18 and 20. Similarly, a painted bus-bar 32 electrically connects the sections 22, 24, 26 and 28. The bus-bar 30 is connected by means of a conductor 34 to one side of a source of electrical energy (not shown) while the bus-bar 32 is connected by means of a conductor 36 to the other side of this source.

A bus-bar similar to the bus-bars 30 and 32 is painted along the common line in which lie the sloping sides of the trapezoidal sections. This bus-bar, however, is discontinuous between each of the sections except the innermost pair of sections 20 and 22. This bus-bar can be formed by painting an entire bus-bar on the plate and then scraping away the undesired portions or by using a suitable mask.

Electrical connectors 38, 40, 42 and 44 are used to connect the various sections 14-28 in pairs. As shown, the conductor 38 is merely a continuation of the bus-bar and joins the sections 20 and 22 in a first innermost pair. This conductor could, of course, be an external conductor. The conductor 40 joins the sections 18 and 24 in a pair, the conductor 42 joins the sections 16 and 26 in a pair and the conductor 44 joins the sections 14 and 28 in a pair. The conductors 40, 42 and 44 are preferably external conductors connected to the bus-bar sections in a conventional manner. These connections result in the formation of a plurality of electrically parallel groups of serially connected pairs of sections. This is illustrated schematically in Figure 2. The sections 14 and 28 will be referred to as the first and last sections, and the other pairs of sections, e.g., 16 and 26 and 18 and 24, will be referred to as inwardly succeeding pairs.

Since each pair of series connected sections are connected in parallel across the source, the voltage drop across each pair will be equal and will be split between the sections in proportion to their resistances. The resistance of each section is defined by the equation.

$$R = r\frac{S}{L}$$

where R=resistance
r=resistivity
S=bus-bar spacing (inches)
L=section width (inches)

The thickness of the coating being constant, the resistivity of both sections is the same if the section widths are equal, in which case the resistance is directly proportional to the bus-bar spacing, and the voltage drop across each section is also proportional to bus-bar spacing. (In the illustrated embodiment the section widths are not equal, for a purpose which will be explained below, but for purposes of general analysis it is convenient to assume that the section widths are equal).

The power produced is found by the equation

$$W = \frac{E^2}{R}$$

where W=power (watts), E=voltage and the power density is found by

$$w = \frac{W}{SL}$$

where w=power density (watts/sq. inch)

Thus, $w = \frac{E^2}{rS^2}$

It can thus be seen that since r and L are assumed to be constant and E and S are directly proportional, the power density in each section is the same, thereby causing equal heating of the entire panel. It should be noted that although only a tapered panel is illustrated and described, the invention is equally applicable to other non-rectangular shapes. It is only necessary that the coating be divided into sections, and the sections serially connected in parallel groups, thereby greatly facilitating control of the total resistance of the groups, and hence the heating effect.

Each panel has a maximum tolerable power density which is determined by the characteristics of the coating, and a minimum tolerable power density which is determined by the amount of heat required to be developed. The distance between the parallel sides of the sections 14-28, hereinafter called their width, must therefore be determined in view of these limits. The minimum power density tolerable is determined from knowledge of the panel configuration and intended function in the expected environment. Such factors as the thickness of the material on either side of the coating, the coefficient of thermal conductivity of these materials, the temperature at the surfaces, the temperature of the outer air, and the heat transfer coefficient at the surface enter into the determination of the minimum power density needed. The manner in which the necessary computations are performed are well known and need not be set forth herein.

Turning now to Figure 3, there is shown a geometric representation of the conductive panel of Figure 1. In this Figure, the height of each of the trapezoidal sections, or the distance between their non-parallel sides, is indicated as S_1, S_2, etc. This distance is measured along the edge of the section, and since the sections are separated only by very narrow isolation lines, the height of one section along its short parallel side can be considered equal to the height of the next succeeded section along its long parallel side. The distance S_1 is taken as the bus to bus spacing at the midpoint, i.e. between sections 20 and 22, each succeeding distance S_2, S_3, ... S_n in the lefthand direction being shorter than S_1. The widths of the sections, or the distances between their parallel sides are indicated at L_1, L_2, L_3, ... L_n etc., each subscript corresponding to the subscript of the height of the section at the side closest to the midpoint. Since the widths of each of the sections in each pair of sections is the same, it is only necessary to determine the widths of the sections proceeding in the lefthand direction. This is done in the following manner.

As previously stated, where r= a constant over the entire area

$$w = \frac{E^2}{rS^2}$$

also, where w_n=minimum power density tolerable in watts per square inch, and

W_{n+1}=maximum power density tolerable in watts per square inch

$$w_n = \frac{E^2}{rS_n2} \text{ and } W_{n+1} = \frac{E^2}{rS_{n+1}2}$$

therefore, $$\left\{ \frac{w_n}{W_{n+1}} \right\}^{\frac{1}{2}} = \frac{S_{n+1}}{S_n} \quad (1)$$

To determine the width of each section, the following relations are used:

$$S_n = S_1 - \tan\alpha\,(L_1 + L_2 + L_3 + \text{—} L_n - 1)$$

$$S_{n+1} = S_n - L_n \tan\alpha$$

$$\therefore S_{n+1} = S_1 - \tan\alpha\,(L_1 + L_2 + L_3 \text{—} + L_n) \quad (2)$$

where α = the angle formed by the intersection of the first and second lines on which lie the non-parallel sides of the sections.

Substituting (2) in (1)

$$\left\{ \frac{w_n}{W_{n+1}} \right\}^{\frac{1}{2}} = \frac{S_1 - \tan\alpha\,(L_1 + L_2 + L_3 \text{ — } + L_n)}{S_1 - \tan\alpha\,(L_1 + L_2 + L_3 \text{ — } + L_{n-1})}.$$

This equation can then be solved for L_n, the width of the nth sections outboard of the centre of the heated area.

$$L_n = [S_1 \cot\alpha - (L_1 + L_2 + L_3 \ldots + L_n - 1)] \left[1 - \left\{ \frac{W_n}{W_{n+1}} \right\}^{\frac{1}{2}} \right]$$

By equating n=1, 2, 3, etc., the width of each pair of sections consecutively outboard is determined until a satisfactory area is encompassed by the heated sections.

If the entire plate has been first coated with the conductive material, the the isolation lines are now scraped from the plate in accordance with the calculated widths of the sections. If a mask is used, the mask is cut to the proper configuration and the material then coated on the plate. If non-rectangular panels other than tapered panels are used, similar calculations must be made to assure that the power density of each section falls within the tolerable range.

From the foregoing description, it can be seen that a conductive panel suitable for use in aircraft windshiels or canopies has been provided that has a controlled power density over the entire heated surface and yet whose conductive material thickness is constant over the entire surface. This constant thickness results in the panel having a constant light transmittance over its entire surface as well as facilitating control of the power density. The provision of a number of coated sections connected in groups eliminates the need for the complex and expensive coating of the conductive material in different thicknesses along the surface of the panel. Although the invention has been described merely in connection with tapered transparent panels, it should be obvious that it is equally useful in any application where controlled power density is desired without a gradient resistivity coating. It should also be apparent that the individual sections could be serially coupled in groups of more than two, each group having the same resistance, and these groups electrically connected in parallel.

WHAT WE CLAIM IS:—

1. An electric surface heater comprising a plate of electrically non-conductive material, and a plurality of discrete sections of conductive material coated on said plate, defining a heated area of non-rectangular shape, the thickness of the material of all the sections being the same, and the sections being electrically connected in groups each comprising two sections in series the groups being connected in parallel across supply terminals.

2. A heater as claimed in Claim 1 of tapered shape, the individual sections being trapezoidal in shape, and each succeeding section having a shorter distance separating the mid points of its non-parallel sides.

3. A heater as claimed in Claim 2 in which the non-parallel sides of the sections lie along two straight lines inclined to each other.

4. A heater as claimed in any of the preceding claims in which the sections are in the form of parallel strips and the first and last sections are connected as a pair in series and the sections of each inwardly succeeding pair are connected in series, each pair constituting one of the said groups.

5. A heater as claimed in any of the preceding claims in which the conductive material of all the sections has the same resistivity.

6. A heater as claimed in any of the preceding claims in which the combined lengths, in the direction of current flow, of the sections in one group is equal to the combined lengths of the sections in other groups.

7. A heater as claimed in any of the preceding claims in which the sections are in the form of parallel strips, and a supply terminal in connected to a conductive strip on the plate contacting the adjacent ends of the sections at one end of the heater, the strip being broken between the two sections making up the innermost pair.

8. A heater as claimed in any of the preceding claims in which the sections of each group are of equal width perpendicular to the direction of current flow.

9. A heater as claimed in Claim 8, in which the widths of the sections in each group differs from group to group, to provide desired control of the heating effect of the different groups.

10. A heater as claimed in any of the preceding claims, in which the sections are in the form of parallel strips, and the width of the central or inner strips is less than the width of the outer or edge strips.

11. A heater as claimed in any of the preceding claims having a trapezoidal shape with two parallel ends, a perpendicular side and a sloping side, the shorter parallel side of each section being substantially equal in length to the longer parallel side of the next section towards the shorter parallel end.

12. A heater as claimed in Claim 11 in which the width of each section perpendicular to the direction of current flow is determined by the equation:—

$$\left\{ \frac{W_n}{W_{n+1}} \right\}^{\frac{1}{2}} = \frac{S_1 - \tan\alpha\,(L_1+L_2+L_3 - +L_n)}{S_1 - \tan\alpha\,(L_1+L_2+L_3 - +L_{n-1})}$$

$$\text{or } L_n = [S_1 \cos\alpha - (L_1+L_2+L_3 - +L_{n-1})] \left[1 - \left\{ \frac{W_n}{W_{n+1}} \right\}^{\frac{1}{2}} \right]$$

where w_n = a predetermined minimum power density,

w_{n+1} = a predetermined maximum power density,

S_1 = the common parallel side length of the innermost pair of sections.

α = the angle of intersection of the perpendicular side and the sloping side,

L_1 = the width of the components along the perpendicular side of the innermost pair of sections,

L_2 = the width of the components along the perpendicular side of the next succeeding pair of sections,

L_n = the width of the components along the perpendicular side of the first and last sections,

L_{n-1} = the width of the components along the perpendicular side next inwardly suceeding pair of sections from the first and last sections.

13. An electric surface heater arranged substantiallly as herein specifically described with reference to the accompanying drawings.

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1,051,777 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

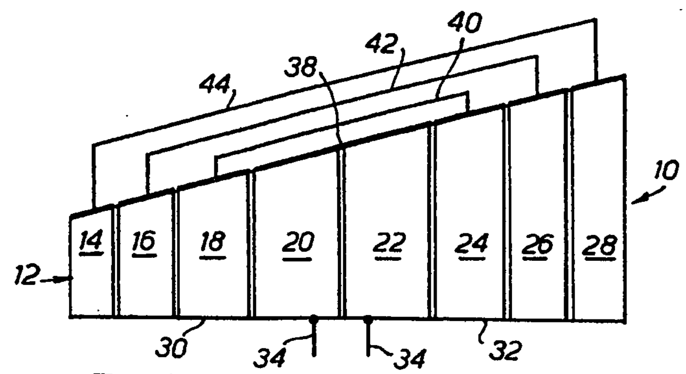

FIG. 1.

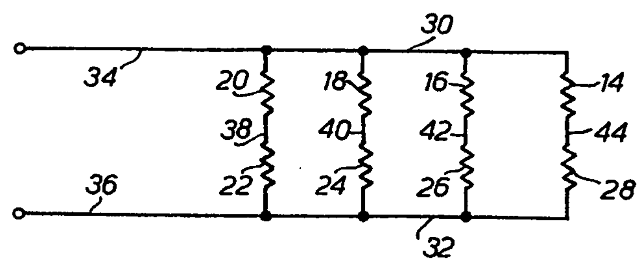

FIG. 2.

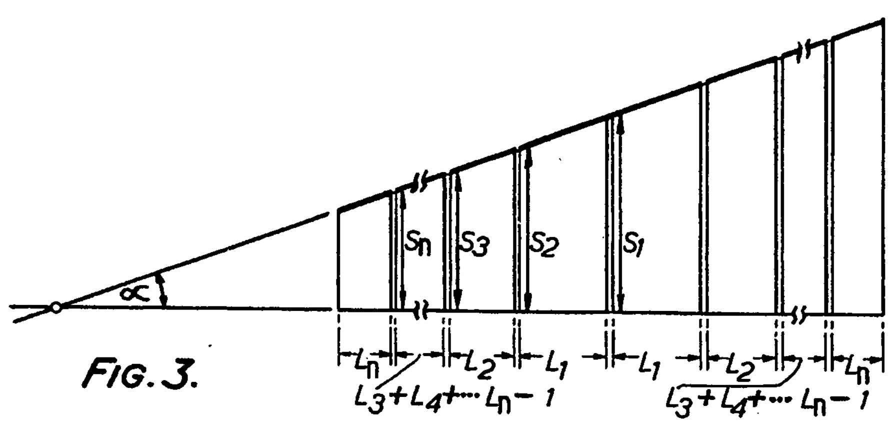

FIG. 3.